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Some airborne observations of condensation nucleus concentration

1. Variations in the vertical

by

G. J. Day

(Meteorological Office)

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Some airborne observations of condensation nucleus concentration

I. Variations in the vertical

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1. Summary

Methods are discussed by which condensation nucleus concentration is customarily measured and attention drawn to the defects of these methods and to the present difficulty in investigating only that portion of the condensation nucleus population which participates in natural condensation processes.

An account is given of the Pollak photo-electric condensation nucleus counter and of its use in a Hastings aircraft of the Meteorological Research Flight in the investigation of the distribution in the vertical of condensation nuclei with radii greater than about 10^{-6} cm.

It was observed that over Southern England nucleus concentration attained a maximum value of 5000 cm^{-3} at 2000 ft with a regular decrease above to 500 cm^{-3} at 10000 ft.

Over a calm sea a maximum concentration of 1500 cm^{-3} was observed at 400 ft followed by a regular decrease to 100 cm^{-3} at 5000 ft. Over a moderately disturbed sea the maximum concentration increased to 3000 cm^{-3} at 600 ft, and over violently disturbed sea surfaces concentrations of 10000 cm^{-3} were observed up to heights of 2000 ft.

In general it was observed that the vertical stability of the air mass had a considerable influence on the local condensation nucleus population.

Proposals are made for further work and for the improvement of the equipment used.

2. Introduction

The concentration of condensation nuclei in the admosphere is a factor of importance in both theoretical and experimental cloud physics. Although extensive surveys have been made at ground level (1) and at mountain stations (2), there is very little information concerning the concentration in the free atmosphere. That which is available is limited to the balloon-ascents of Wigand (3) over Europe, and to the observation of sea-salt nuclei over the American continent (4) and over the Australian continent (5).

Attempts have been made by the Meteorological Research Flight to measure the concentration of condensation nuclei from an aircraft using a standard type of Aitken counter as used by e.g., Scrase (6). This instrument has several limitations; the chief of these is the small number of nuclei and the consequent necessity for several samples to be made in the establishment of a statistically reliable count. Each sample may require manipulation and

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observation lasting about a minute and, as about twenty samples are usually required for each count, the observation is of the average condition over some tens of minutes. For some purposes such a rate of sampling is acceptable for ground level experiments, but in the case of experiments in aircraft it represents sampling on a scale of about fifty miles. Every atmospheric variable investigated so far has been notable for its extreme variability in space on a considerably smaller scale than this and there seems no reason to suppose that condensation nucleus concentration should be an exception. The coarse sampling obtained with an Aitken counter was, therefore, considered unacceptable and a more suitable instrument sought.

Consideration was given to recent variants of the basic Aitken counter, such as that of Pollak (7), but all suffered from the limitation noted above. Hence, it was decided to adopt the photo-electric condensation nucleus counter of Pollak (8) in which the sample volume is about a litre compared with about 10 cm^3 in the case of the Aitken counter and its variants.

A copy of the Pollak instrument was made in the workshops of the Meteorological Research Flight and calibrated in the laboratory of Senior Prof. L.W. Pollak at the Institute for Advanced Studies in Dublin. It was found to have a calibration identical with that of the original instrument within the working range of 10^2 to 5 x 10^5 nuclei cm^{-3} with a probable experimental error of $\pm 5\%$.

The instrument was installed in the Hastings aircraft of the Meteorological Research Flight and a preliminary series of observations made at different altitudes. These flights were principally over Southern England and are described in Part I of this report. Part II will discuss variations in the horizontal over the British Isles and Part III the variations at particular heights in the vicinity of Farnborough (Hants) during January, 1956.

Whilst the data so far obtained do not lead to a complete picture of the variations of concentration and the typical concentrations of condensation nuclei to be expected in all representative geographical and synoptic situations, it is considered that this is an appropriate stage to report on this work.

In all this work the question arises, what is counted by an instrument such as the photo-electric counter? The degree of supersaturation within the counter at the moment of operation is, perhaps, two or three hundred per cent compared with a maximum of, perhaps, 0.1% experienced during natural condensation processes. The counter samples all condensation nuclei having radii greater than 10^{-6}cm whereas natural condensation processes are probably concerned mainly with nuclei of radius greater than about 10^{-4}cm.

The view has been vigorously advanced by Dessens (9) and others that the selection of such a wide class of nuclei renders all observations with expansion-type instruments worthless for most purposes in the cloud physics context. As will be seen later in this report this view is at least open to question in the special circumstances of these flights. Further, it is suggested that, in the absence of more detailed and unassailable sources of information, the restricted information presented, in this report, is of value at the present time in providing an upper limit to the concentration of condensation nuclei available for natural condensation processes. Moreover, data with regard to source regions and distributions of nuclei in the vertical are of considerable interest in other branches of physical meteorology, e.g., air pollution, light scattering, radiative diffusion, etc. - in fact they are relevant to all work involving studies of aerosols.

3. The instrument

The instrument and its calibration have been discussed by Pollak (7). The Meteorological Research Flight version, though similar in essentials, differs considerably in constructional details from that described in (7), ease of maintenance and absolute rigidity under flight conditions being desired. An instrument very similar to that constructed at the Meteorological Research Flight was described by Pollak and O'Connor (10) recently.

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The instrument is mounted with its pump and filter units in the wardroom of a Hastings aircraft (Fig. 1). It is served by an air intake mounted about 3 m ahead of the propellers and about 15 cm away from the aircraft skin. A duct about 1 cm in diameter and 30 cm long connects the instrument to the intake.

Prior to an observation, air is allowed to flow through the instrument, under the ram pressure due to the aircraft motion, until about twenty volume changes have taken place. The instrument is then isolated and air is pumped through the filter unit into the fog chamber until a pressure of 1.22 x ambient pressure has been attained. The air in the fog chamber becomes saturated by evaporation from the moist, porous lining of the fog-chamber, and is then allowed to expand adiabatically to ambient pressure. The extinction coefficient of the fog thus formed is determined by comparison of the steady signals, before and after expansion, from a photo-cell mounted at one end of the chamber and illuminated by a parallel beam of light from an illuminator at the other end. Disturbing effects due to condensation on to the glass end plates of the fog-chamber are avoided by the use of electrically heated glasses.

The entire sequence of operations occupies about 1.5 min so that samples are conveniently taken every 2 min, i.e., every 5 mi. at the normal cruising speed of the Hastings aircraft. Proposals are made below by which it is thought that the sampling interval may be reduced to about 1.5 mi.

Calibration is achieved by comparing the instrument with a photographically recording, improved Aitken-type instrument, using air drawn from a large gas-holder, thereby ensuring the constancy of nucleus-concentration necessary for accurate measurements with the latter, absolute, instrument. The size-distribution of these nuclei, which are drawn from the heavily polluted air of the laboratory, probably differs from that of naturally occurring nuclei but work by Howell (11) suggests that this is not likely to affect the equilibrium value of fog-droplet size distribution and hence should not affect the calibration.

The accuracy quoted above is probably valid for comparisons between instruments of similar fog chamber design or for work with one instrument but the absolute accuracy is probably smaller. A defect of the instrument, which adversely affects its accuracy, is that the fog formed begins to disappear after a very short time - usually 2 to 3 sec. A method has been devised by Pollak (10) since this work, however, by which this defect may be overcome.

4. The investigations

An attempt was made to survey variations in condensation nucleus concentrations in the vertical and in the horizontal over the British Isles. Only variations in the vertical - which were studied mostly over Southern England - will be discussed here.

The flights fall into two main groups, which may be subdivided:-

A. Investigation of variations in the vertical over land

B. Investigation of variations in the vertical over:-

(i) Calm sea

(ii) Disturbed sea.

In these flights it was customary to make observations at nominally constant ground position and height. Over land, samples were taken at vertical intervals of 500 ft up to 10000 ft, and occasionally at irregular intervals thereafter to 20000 ft. Over the sea, samples were taken at 100 ft vertical intervals to 1000 ft, 200 ft intervals to 2000 ft, and occasionally at irregular intervals above this height.

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5. The observations

A. Variations in the vertical over land

The ascents in this group total 29.

The observations are given in Table 1a which contains also the mean concentration at each height (all cases being considered), the maximum concentration at each height and a statement indicating the character of the air mass on each occasion. Where appropriate a further table, 1b, contains simultaneous observations of air temperature.

Considered individually, the ascents have little in common and are remarkable chiefly for their great variety. The work of Sagalyn and Faucher (12) suggests that some, at least, of this variation between apparently comparable cases may be due to a diurnal variation in the processes by which nuclei are dispersed. It would seem desirable that further flights, specifically concerned with this aspect, should be made.

Fig. 2a shows the variation of the mean concentration and of the maximum concentration with height. Generalisations are necessarily imprecise, but as far as can be judged from this series of observations, it appears that over Southern England:-

(a) Mean concentration of condensation nuclei decreased from between 7000 and 8000 nuclei cm^{-3} near the surface to about 1000 nuclei cm^{-3} at 10000 ft and 600 nuclei cm^{-3} at 20000 ft.

(b) On occasions the concentration reached 20000 nuclei cm^{-3} at heights up to 6000 ft but it was rare for the concentration to exceed 4000 nuclei cm^{-3} at heights above 10000 ft.

(c) The variation of concentration with height on individual occasions was by no means simple and appeared to be considerably influenced by the vertical stability of the air mass. Levels of increased vertical stability were usually accompanied by increases in nucleus concentration. On the macroscopic scale, increases in nucleus concentration were, in extreme cases, marked by haze layers.

The variation of both temperature and concentration in the vertical observed in certain typical flights is presented graphically in Fig. 2b.

(d) On rare occasions during this series of flights the concentration decreased regularly with height, usually from about a few thousand nuclei cm^{-3} near the ground to less than 100 nuclei cm^{-3} at 6000 ft. The ascent of 22.3.55 (Fig. 2b) was typical of such conditions. In general, variations with height of this form were observed on days of convective instability and, therefore, probably result from an efficient dispersal of nuclei from sources at ground level. The rarity of such cases in this series probably reflects the rarity of convective instability during the period of this investigation. An interesting occasion is that of 20.6.55 when several ascents were made at points around the centre of a small depression passing across the North Sea. One of these ascents, made over Holland, is illustrated in Fig. 2c and shows a marked change in variation of nucleus concentration with height at about 13000 ft. This may be identified with the penetration of the lifted warm sector of the occluded frontal depression and suggests that the different air masses were here characterised by nucleus concentrations differing by about a factor of four at medium altitudes.

B. Ascents over sea surfaces

These were made with two purposes in view:-

(i) To determine the nucleus concentration in relatively unpolluted air over the undisturbed sea and the variation of concentration with height.

(ii) To determine the effect of the production of sea salt nuclei by a disturbed sea surface on the nucleus concentration in the air above, and the variation of this effect with height. Flights were made over rapidly shoaling water, such as the Shingles Bank, or at places where tidal effects give rise to a locally disturbed sea surface, as in the vicinity of Portland Race.

Treating these two sections in turn:-

(i) Undisturbed sea. It was difficult to ensure that ascents were made over completely undisturbed water or in air unpolluted by land sources and the results are imprecise to this extent.

This group contains five sets of observations, two of which were made on the same flight. The results are given in Table 2a which also contains the mean concentration observed at each height and an indication of the vertical stability of the air mass. Fig. 3a illustrates the variation of the mean concentration with height and Fig. 3b represents the individual ascents.

The ascent of 6.4.55 made in the vicinity of the Scilly Isles and illustrated in Fig. 3b (iv) is typical of this group. The concentration of condensation nuclei rose from about 600 cm^{-3} at 100 ft to a maximum value of about 1400 cm^{-3} at 300 ft, above which there was an irregular decrease of concentration to a few hundreds per cm^3 at heights above 1000 ft. Stabilisation of the temperature lapse rate at 900 and 2000 ft was associated with maxima in the nucleus concentration variation with height.

In this series of flights the greatest concentration observed was about 3600 nuclei cm^{-3} at about 600 ft in the vicinity of the Scilly Isles, (Fig. 3b (iii)).

(ii) Disturbed sea. a. As a consequence of the synoptic conditions prevailing when an aircraft was available for this work, the data are weighted towards moderate wind speeds.

Five ascents were made and the observations are recorded in Table 2b, which also contains the mean concentration observed at each height and an indication of the vertical stability of the air on each occasion. In obtaining mean concentrations the exceptional case of 6.10.55 has been omitted and is dealt with separately in 5.B.(ii).b below.

The ascent of 11.11.55 is typical of this series and is illustrated in Fig. 3c (iii). Nucleus concentrations of about 1900 cm^{-3} were observed at about 100 ft and a maximum concentration of about 2900 cm^{-3} at 200 ft above which height there was a more or less regular decrease to slightly more than 1000 cm^{-3} above 1000 ft. The maximum concentration was observed in a layer of increased stability and similar increases in or below levels of increased stability were observed at 1200 and 1600 ft.

b. The ascent of 6.10.55 illustrated in Fig. 3c (v) was made over the Goodwin Sands on an occasion when the wind speed was between 25 and 30 kt and sea spray was observed to reach about 500 ft. Although observations were made downwind of Greater London it is not thought that there can have been any significant pollution since visibilities of about 10 mi were reported.

On this occasion condensation nucleus concentrations of more than 10000 cm^{-3} were observed in the layer between the surface and 2500 ft, a maximum concentration of about 12500 cm^{-3} being observed at about 1400 ft. At 4000 ft the concentration remained greater than 5000 nuclei cm^{-3}.

Once again maxima in the variation of concentration with height were found at, or immediately below, levels of increased stability, e.g., at 200, 600, 800 and 1400 ft.

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In this case there can be no doubt that there was production of a considerable number of nuclei at the sea surface, which was violently disturbed.

Considering the results from the nine flights of this group as a whole, it is possible to reach the following tentative conclusions:-

1. . Concentration of nuclei over the sea, remote from land contamination, at levels where the bases of low clouds are usually found - say 2000 ft - is normally a few hundreds per cm^3.

2. Above seas which are moderately but not violently disturbed - say for wind speeds less than 15 to 20 kt in the absence of marked tidal or shoal water effects - concentrations appear to increase from between 1000 and 2000 nuclei cm^{-3} just above the surface to a maximum of between 2000 and 3000 cm^{-3} at about 600 ft and thereafter decrease to a few hundreds per cm^3 at about 3000 ft.

3. Comparison of Tables 2a and 2b suggests that there is a detectable production of condensation nuclei by moderately disturbed sea surfaces.

4. The unusually large concentrations of nuclei observed over a violently disturbed sea surface, in excess of 10000 cm^{-3}, must be ascribed to sea spray processes.

5. As in the case of ascents over the land, levels of increased vertical stability are usually marked by increases in condensation nucleus concentration.

These conclusions are based on a small, unevenly weighted sample and should not be regarded as firm. More ascents will be necessary to establish them securely. In particular it seems desirable that ascents should be made over the disturbed seas associated with vigorously developing Atlantic depressions at some distance from the land and in a wide range of wind speeds. It should then be possible to determine a critical wind speed for effective nucleus production by the sea spray mechanism.

6. Discussion

Squires (13) and Durbin (14) have reported droplet concentrations in cumulus clouds in maritime air of up to 300 cm^{-3}. It would appear, then, from the observations reported here that over the sea, and probably over the land away from pollution, the concentration of nuclei is comparable with that of cloud droplets, i.e., the indication is that probably a third of the nuclei sampled are operative in important meteorological processes. The validity of Dessens' (9) criticism, referred to in Section 2 above, then, may be questioned in these special circumstances. Indeed, over the sea at least, the inability of present droplet sampling systems to capture droplets of diameter less than about 3 μ may suggest that virtually all the nuclei sampled in this series of flights are active in natural condensation processes.

An outstanding feature of the concentrations observed up to medium altitudes was the inhomogeneity of the atmosphere, with respect to condensation nucleus concentration, in both time and space.

The results given above may be compared with those of previous workers. The only comparable European observations are those of Wigand (3) who made 14 balloon ascents in anticyclonic conditions over an industrial region of Central Europe. The mean concentrations determined by Wigand are plotted in Fig. 2a and will be seen to be consistent with the observations reported above. Observations by Amelung and Landsberg (18) during motor trips up the slopes of the Taunus Mountain in Germany show increases in concentration with increasing vertical stability of the atmosphere in a similar fashion to the aircraft ascents above. There appear to be no published ascents over sea surfaces adjacent to Europe.

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7. Suggestions for further work

It is suggested:-

a. That further attention be paid to the conditions over disturbed sea surfaces under a representative range of wind speeds. In particular it is suggested that ascents should be made to greater heights, say 10000 ft, and in regions remote from possible polluting sources. The vicinity of vigorously developing Atlantic depressions would appear suitable.

b. That future work should be accompanied by direct sampling of sea salt nuclei, sampling by the Liesegang Ring (16) system for chemical identification of radicals, and by some attempt at size discrimination of the condensation nuclei sampled, as for instance, by the method of Rich (17).

c. That modifications be made to the equipment in use, as follows:-

(i) the manually-operated valves should be replaced by automatically controlled solenoid-operated valves thus permitting an economy in crew.

(ii) an attempt be made to humidify the sampled air during the passage to the fog chamber thus increasing the possible speed of operation.

An instrument embodying some of these proposals is in course of development for ground use and will be reported on at a later date.

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Table 1A Variation of concentration with height over land (Southern England)

Date	Concentration of condensation nuclei (Radii > 10^{-6} cm) – Nuclei cm^{-3}																				
Height (ft)	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500	11000
21.3.55			13100	18200	17200	10700	7340	7080	9400	16300	15300	8050	580		250	100						
			17300	15300	17700	11400	10100	9760	12900	14000	18700	10400	1380									
a.m.				12900	16700	10100	8600	7560	15800	17200	10900											
25.3.55	6970	760	250		370	370	150	140	140	180	290	370										
p.m.										520			1070			100						
a.m.																						
28.3.55	4390	2380	2850	3490	1100	780	4700	5040	1070	120												
p.m.	8930	2690	1420	2570	2860	850		1300	700	1070	860	640	100	100	100							
22.3.55		3220		1080				3400		370			250						1110		840	270
	2680			2470		1820		2060		840		120		1330				280				100
		780			100		550		360	210	360					100				280		100
12.4.55		6800	6700	3830	6660	4740	1850	2420	100	100												
13.4.55			4400	6700	4700	1820	2040	2450														
14.6.55						260		440	880	2100	690	660	260	2150		140	120					
15.6.55				10300		1730		1480		160		540		480		650		360		1350		360
20.6.55			6060				6600					4320						2110			970	
			2340			970	640				490			540		760		780			540	
				4250	3700						880				850				660			
		3220			1930				2290		750		820			510	1930			650		
23.6.55		3430		690		100		810		790		220		430		410		5160				280
27.6.55			540	12800	8600																	
		11200	4060	5900	8000	1000	2230	890	1250	900	900											
a.m.		5120	6260					1950				800										
13.7.55		11300		15000		12900		7450		2470		2730		680		580		390		740		580
p.m.				2230	2780		1870	1770			470			800		200						
15.7.55		1040		1300		640		160		2100		110		100		100		100		100		400
20.7.55		16000		13300		5400		1840		1380		390		390		730		5400		13300		11000
25.7.55	12800	25000			16400	13600												210		100		
		24000		12700		12100		7080		5720		520		300		540		390		1840		1290
26.7.55		7700		5100		1900		800		300		300		360		1330		1080		1060		1290
4.8.55		9800		7560		9960		9200		3430		3290		1950		1860		970		500		390
9.8.55										1600						1720						
10.8.55		3800		2800		1560		1100		800		290		260		330		340		510		540
Mean) concen-	7150	7680	5440	7300	7260	4760	3590	3310	4070	3050	4220	1990	640	710	400	610	1030	1350	890	1860	710	1360
Max.) tration	12800	25000	17300	18200	17700	13600	10100	9760	15800	17200	18700	10400	1380	2150	850	1860	1930	5160	1110	13300	970	11000
Min.)	2680	760	250	690	100	100	150	140	140	< 100	290	110	250	< 100	< 100	< 100	< 100	< 100	660	< 100	540	< 100
No. of cases	5	18	12	22	15	22	13	23	11	23	12	17	7	14	3	17	2	13	2	11	3	12

Contd.

Table 1A Variation of concentration with height over land. (Southern England)

Date	Concentration of condensation nuclei (Radii > 10^{-6} cm) – Nuclei cm^{-3}																	
Height (ft)	11500	12000	12500	13000	13500	14000	14500	15000	15500	16000	16500	17000	17500	18000	18500	19000	20000	Vertical stability of air, etc.
21.3.55																		DALR to 5000 ft. Inversion above.
a.m.																		
23.3.55																		Inversion to 2000 ft. SALR to 10000 ft.
p.m.																		
a.m.																		DALR to 3500 ft. SALR above, no marked inversion. Inversion to 5500 ft, SALR to 10000 ft, inversion to 12000 ft.
28.3.55																		
p.m.																		
22.3.55		1090		100														
		100																
		100																
12.4.55																		DALR to 4000 ft, inversion of 7°F from 4000 to 5000 ft, DALR to 5000 ft, inversion above DALR.
13.4.55																		
14.6.55																		
15.6.55		1410		690		900		550		340		610		390		650	610	DALR to inversion at 4000 ft SALR with inversions at 6000 and 10000 ft.
20.6.55		1090										1480				1010	790	Stable to isothermal between
		1090	660	730	750	670		620		370	1140		1030	1300		860	550	5500 and 7500 ft. Further
	530			660														stable layer between 10000 and
	680			610		670		620										11000 ft.
23.6.55		500		540		610		210		610		1330		220		780	550	Inversion to 2000 ft, DALR above with inversions at 7500, 14000 and 16000 ft.
27.6.55																		DALR to inversion at 8500 ft.
a.m.																		DALR above. Small stable layer at 7000 ft.
13.7.55		470		680		470		800		680		390		350		530	920	DALR to an inversion at 4000 ft, DALR from 6000 ft with small inversion at 12000 ft.
p.m.																		
15.7.55		100																Stable to inversion at 11500 ft.
20.7.55		3050		1840		3430		2690										DALR, small inversion from 10500 to 11000 ft.

Contd.

Table 1A Variation of concentration with height over land (Southern England)

Date	Concentration of condensation nuclei (Radii > 10^{-6} cm) - Nuclei cm^{-3}																
Height (ft)	11500	12000	12500	13000	13500	14000	14500	15000	15500	16000	16500	17000	17500	18000	18500	19000	20000	Vertical stability of air, etc.
25.7.55	200	3170		1480		640		300		390		1380		1110		610	870	DALR to strong inversion at 6000 ft. Isothermal from 8000 ft to 9000 ft.
26.7.55		1960		1700		2230		1970		1010		1960		730		840	730	DALR to inversion at 2000 ft. Stable above 4000 ft.
4.8.55		500		390		800		190		330		460		820		460	580	Stable to inversion at 8000 ft. SALR above 8500 ft.
9.8.55		420										350						Barely stable.
10.8.55																		Isothermal from 10000 to 10500 ft.
	470	1070		860		1160		880		530		990		700		790	700	Mean concentration
	680	3770		1840		3430		2650		1010		1960		1300		1010	920	Maximum concentration
	1200	< 100	660	< 100	750	470		210		330	1140	350	1030	220		460	550	Minimum concentration
	3	14	1	11	1	9		9		7	1	8	1	7		8	8	Number of occasions

Table 1B Air temperatures corresponding to data of Table 1A

Date	Air temperatures, degrees Fahrenheit																			
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500
21.3.55			40.1	37.1	35.0	33.6	31.7	29.4	27.1	24.2	21.7	19.9	21.0		17.8	14.3					
a.m.																					
25.3.55		44.6	46.1	46.6	48.0	51.8	52.7	50.8	49.8	48.1	46.7	44.4									
p.m.				59.7	58.1	57.0	54.7	52.2	49.6	48.5	46.3	45.4	43.5	40.7	38.5	38.4	37.2	35.2			
a.m.																					
28.3.55	35.0	36.3	33.3	31.6	29.1	27.8	24.3	21.8	22.1	22.2											
p.m.		37.5	36.0	33.0	30.8	28.0		23.9	23.6	17.9	18.4	17.6	17.0	16.7	15.8						
22.3.55		37.8		32.4		30.7		31.7		31.5		26.3		25.9				20.2		16.7	15.3
12.4.55		53.3	50.7	49.1	46.3	41.9	41.5	37.6	46.6	45.6											
13.4.55			54.2	51.5	48.3	46.0	43.7	41.7													
14.6.55			53.0			57.0		55.2	54.1	52.0	50.7	48.5	47.9	44.7		41.5	41.7				
15.6.55				58.0		54.0		48.0		50.0		45.1		44.0		43.2		39.5		36.0	
20.6.55					47.0					43.0	43.0	43.0	42.0		36.0						26.0
23.6.55		55.0		57.7		57.0		53.0		50.0		47.0		40.2		42.2		41.0		36.0	
27.6.55					53.0						39.0		37.0					29.0	31.0		
a.m.																					
13.7.55		71.0		66.0		60.9		57.0		55.0		54.0		47.0		43.9		39.0		34.6	
p.m.			71.0		69.1	60.6	59.5			54.4			49.0			44.9					
15.7.55		72.0		66.0		62.0		57.5		54.9		52.0		48.1		46.1		41.5		48.9	
20.7.55		64.1		56.8		52.0		47.0		41.1		46.6		46.9		43.6		40.0		35.0	
26.7.55		55.0		49.5		45.9		50.0		46.9		44.1		40.0		34.4		32.1		30.2	
25.7.55	58.0		58.0	59.0	60.0	61.0	60.0	56.0	56.0	56.0	55.0		51.0		48.0					38.0	
4.8.55		61.4		58.0		53.1		48.2		43.9		39.0		35.9		34.2		38.6		35.4	
9.8.55										45.5											
10.8.55				56.0				48.0					38.0		35.0					23.0	

Contd.

Table 1B Air temperatures corresponding to data of Table 1A

Date	Air temperature, degrees Fahrenheit																	
	11000	11500	12000	12500	13000	13500	14000	14500	15500	16000	16500	17000	17500	18000	18500	19000	19500	20000	Height (ft)
21.3.55 a.m.																			A
25.3.55 p.m.																			A
28.3.55 p.m.																			A
22.3.55			9.9		6.6														A
12.4.55																			A
13.4.55																			A
14.6.55																			A
15.6.55	36.0		33.5		28.8		26.5			17.8		15.0		11.5		9.0			A
20.6.55				17.0						+1.0		-9.0			-18.0				R.S.
23.6.55	33.0		30.5		25.5		24.0		20.2	17.7		17.0		13.2		9.8		5.1	A
27.6.55 a.m.						14.0		6.0				-11.0		-18.0	-20.0				R.S.
13.7.55 p.m.	31.1		27.5		26.0		22.0		19.0	14.1		11.4		8.0		2.8		-0.6	A
15.7.55	34.2		35.1																A
20.7.55	31.0		29.0		22.1		25.0		22.9										A
26.7.55	26.2		23.9		21 1		17.3		13.0	10.0		6.5		2.9		-2.0		-6.6	A
25.7.55				23.0	22.0	20.0				6.8		-3 0	-4.0						R.S.
4.8.55	33.0		31.0		26.9		25.0		21.6	18.1		13.7		9.1		6.9		3.0	A
9.8.55									20.6			9.0		5.5			-0.1	-2.0	A
10.8.55	23.0		19.0	14.0			6.0		-3.0			-13.0						-40.0	R.S.

A. = Simultaneous aircraft observation

R.S. = Most appropriate radio-sonde observation

Table 2A Variation of concentration with height over calm sea

Date	Concentration of condensation nuclei - Nuclei cm^{-3}																								
	100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
28.3.55	790	850	1240	790	270	1240	1510		1210		1420	1620	1720	1540											
26.7.55	18700	19400	17500	18200	38000	2780	4020	7780	7450	7450	3070	14400	10300	16300	2470										
6.4.55	680		3580		940		400		210		220	120			150	180	100	830	250						
6.4.55	580		1190		810		990		270	120		280			330	150	150								
16.5.55	1200																	100		100	100		100	120	500
Mean concentration	810	850	2000	790	670	1240	960		560	120	820	670	1720	1540	240	165	125	470	250	100	< 100		< 100	120	500
Maximum concentration	1200	850	3580	790	940	1240	1510		1210	120	1420	1620	1720	1540	330	180	150	830	250	100	< 100		< 100	120	500
Number of cases	4	1	3	1	3	1	3		3	1	2	3	1	1	2	2	2	2	1	1	1		1	1	1

Contd.

Table 2A Variation of concentration with height over calm sea

Date	Remarks	Vertical stability, etc.
28.3.55	Shambles L.V. to Shingles L.V.	Stable lapse rate
26.7.55	Off Brighton, heavy pollution	
6.4.55	Off Scilly Isles	)DALR to 1000 ft. isothermal to
6.4.55	Off Scilly Isles	)1200 ft. DLAR above)
16.5.55	East of Tiree	Stable to inversions at 3000 and 4500 ft. DALR above to inversion at 6000 ft
		Mean concentration at height, excluding 26.7.55
		Maximum concentration at height, excluding 26.7.55
		Number of cases

Table 2B Variation of concentration over disturbed sea

Date	Concentration of condensation nuclei - Nuclei cm^{-3}																					
	100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2500	3000	3500	4000	4500	5000	5500	6000
25.3.55				2090	5910	7450	1270	6810	710	1050	910	540	720	370	460	290	280	370	120		140		
28.3.55	1130	860		940	820	1020	2070	1410		1950	1300	2490	1140	1380									
19.7.55	1550	1460	1980	1210	1550	1450	1760	1170	990	1050	1320	950			1050	1380							
11.11.55	1890	2260		2250		1670		1460		1200	1440	1050	1290	1130									
6.10.55	10450	12600	10400	9860	10100	11700	10400	11700	11500	10800		12700	12600	10900	11100	10200	9090	5960	5960				
Mean concentration	1530	1530	1980	1620	2760	2890	1680	2710	850	1310	1240	1160	1050	1050	760	840	280	370	120		140		
Maximum concentration	1890	2260	1980	2250	5910	7450	2070	6810	990	1950	1440	2090	1290	1380	1050	1380	280	370	120		140		
Number of cases	3	3	1	4	3	4	3	4	2	4	3	4	3	3	2	2	1	1	2		1		

Contd.

Table 23 Variation of concentration over disturbed sea

Date	Remarks	Vertical stability, etc.
25.3.55	Bournemouth to Needles, over Shingles Bank	Complex inversion to 1200 ft. Further inversions at 2500 and 3500 ft
28.3.55	Shambles L.V. to Portland Point	DALR above
19.7.55	Goodwin Sands, drying, sea moderate	Isothermals around 550 and 750 ft, stable lapse elsewhere
11.11.55	Portland Race	Inversion to 200 ft, DALR with stable layers elsewhere
6.10.55	Goodwin Sands, spray to 500 ft	Inversion to 200 ft and around 900 ft. Isothermal between 1600 and 2000 ft, DALR elsewhere
		Mean concentration at height, excluding 6.10.55
		Maximum concentration at height, excluding 6.10.55
		Number of cases

FIG. 1. PHOTO-ELECTRIC CONDENSATION NUCLEUS COUNTER MOUNTED IN WARD-ROOM OF HASTINGS AIRCRAFT

Nº MET. RES. FLT.
DR.
TR. O.W.H.
CH.
APP.

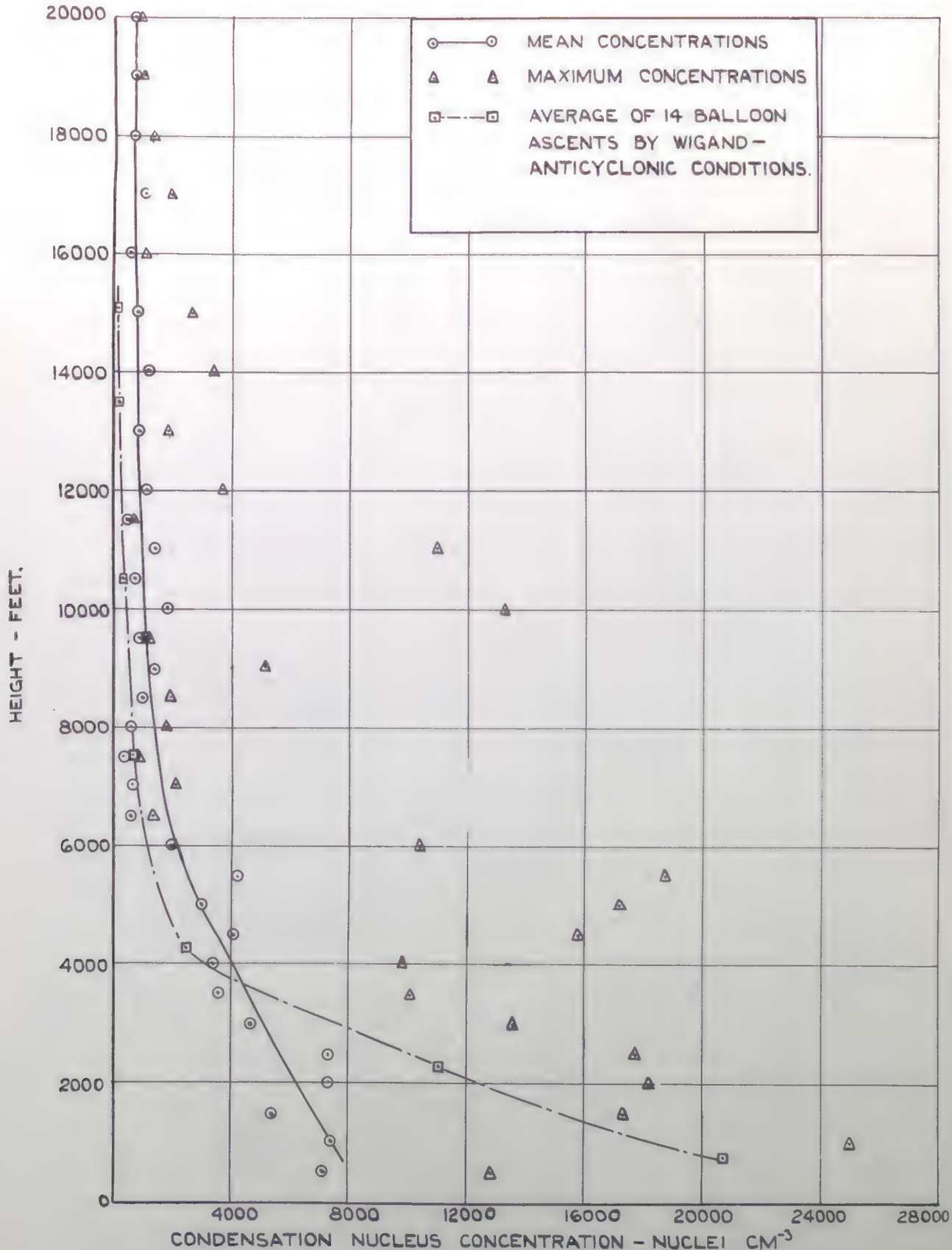

FIG. 2 a. VARIATION OF CONDENSATION NUCLEUS CONCENTRATION WITH HEIGHT OVER LAND.

Nº MET. RES. FLT.
DR.
TR. O.W.H.
GH.
APP.

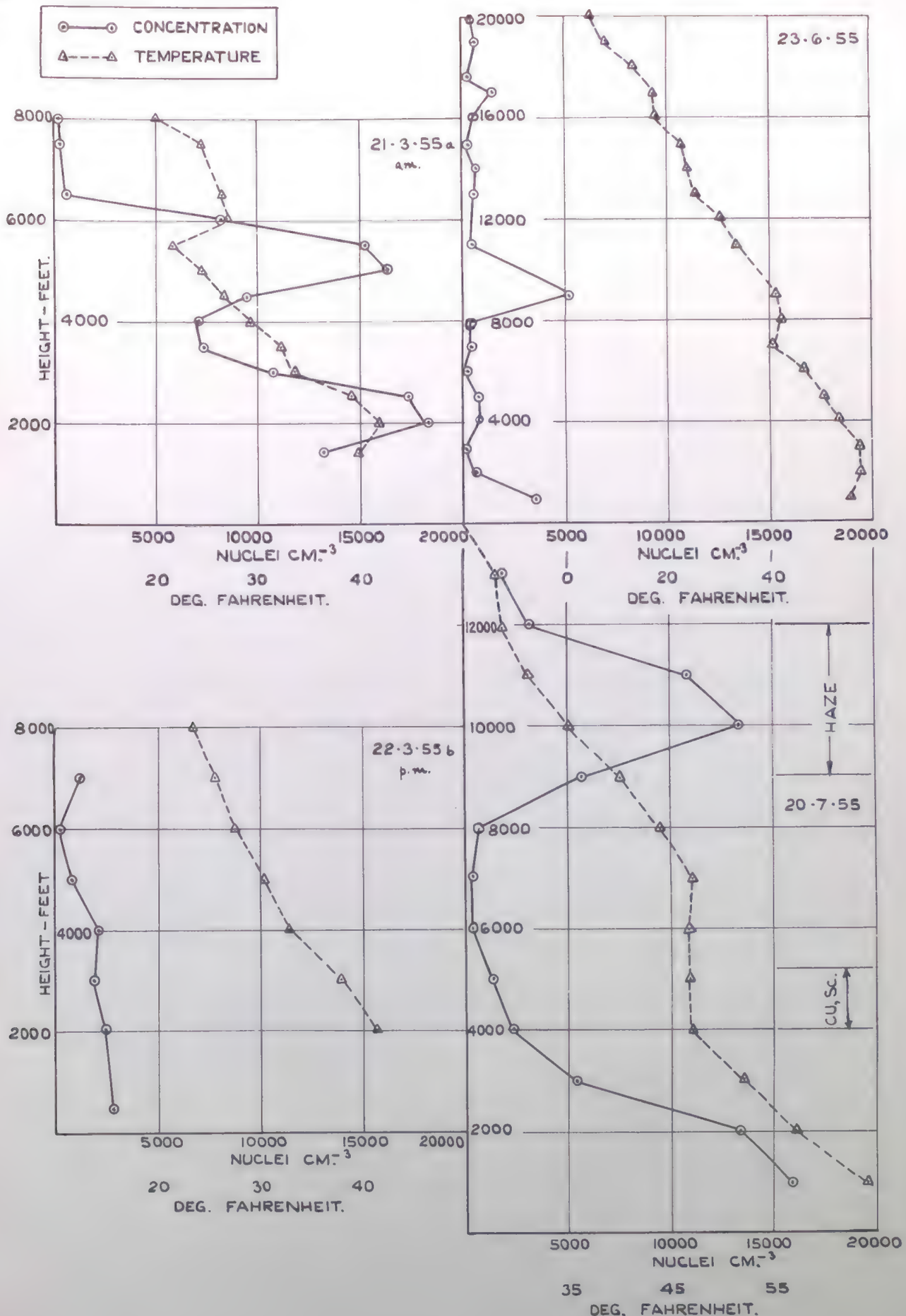

FIG. 2b. INDIVIDUAL EXAMPLES OF VARIATION OF CONDENSATION NUCLEUS CONCENTRATION WITH HEIGHT.

Nº MET. RES. FLT.
DR.
TR. O.W.H.
CH.
APP.

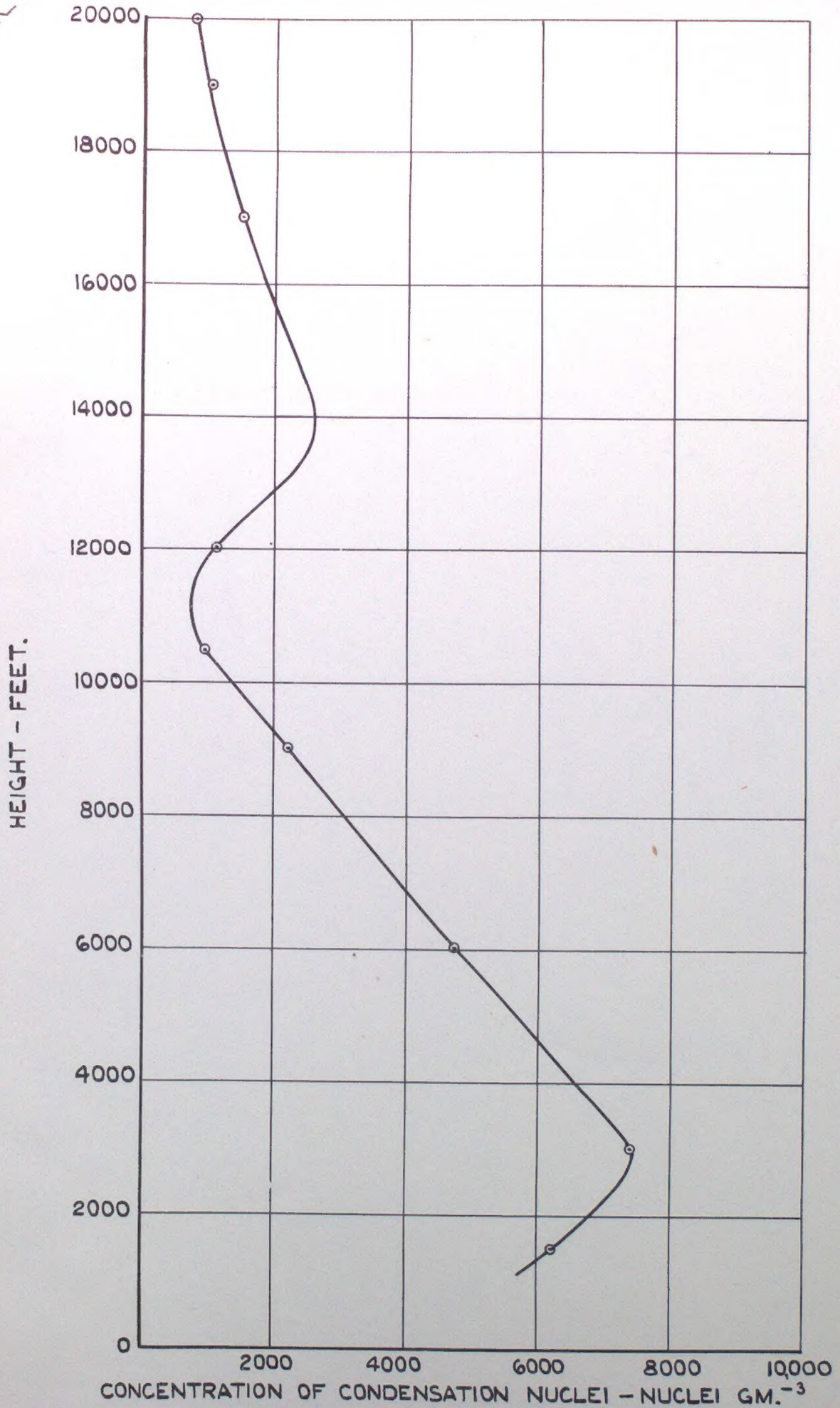

FIG. 2 c. ASCENT THROUGH A FRONTAL SURFACE, NEAR THE DUTCH COAST - 20·6·55.

Nº MET. RES. FLT.
DR.
TR. O.W.H.
CH.
APP.

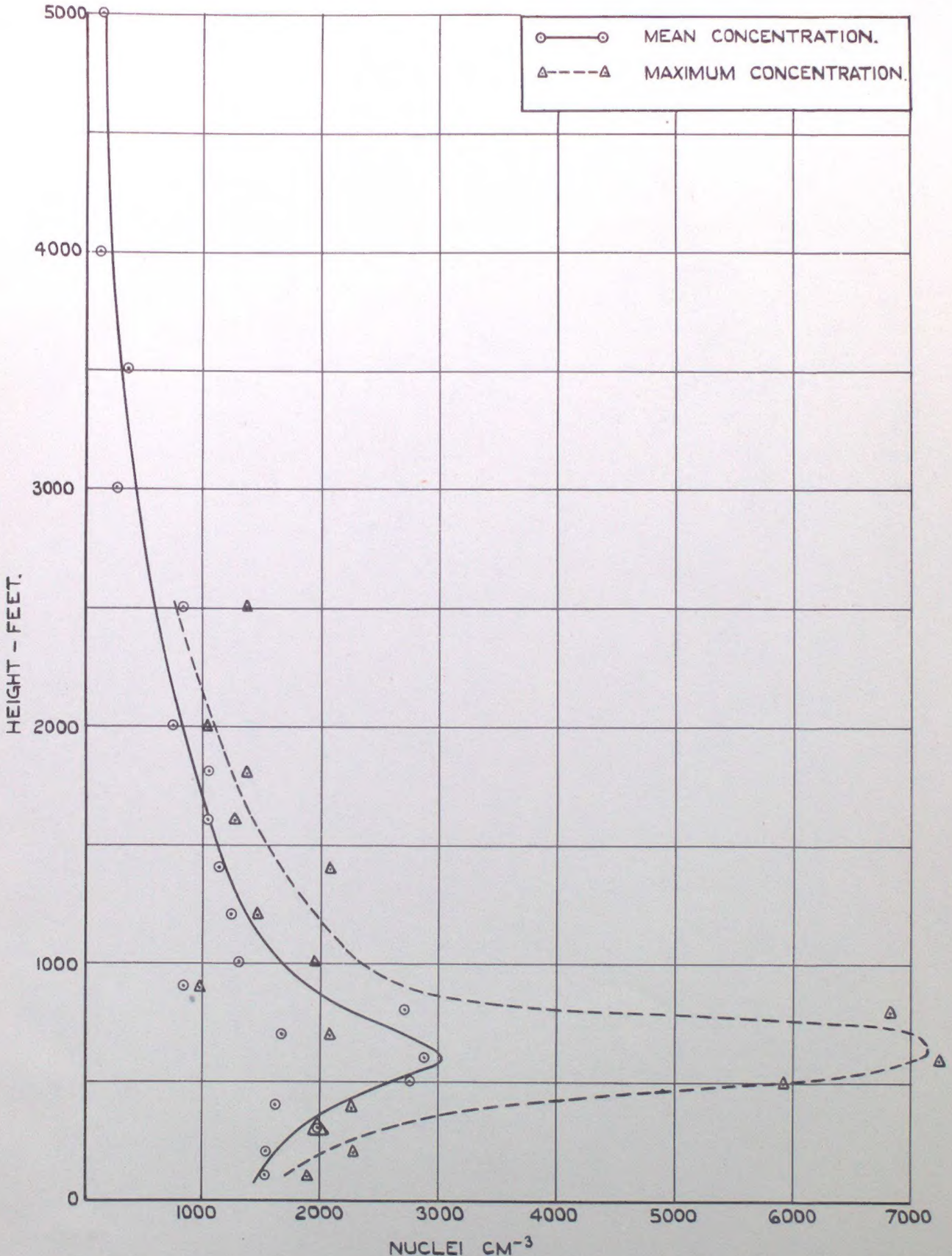

FIG. 3 a. VARIATION OF CONDENSATION NUCLEUS CONCENTRATION WITH HEIGHT OVER SLIGHTLY DISTURBED SEA.

Nº MET. RES. FLT.
DR.
TR. O.W.H.
CH.
APP.

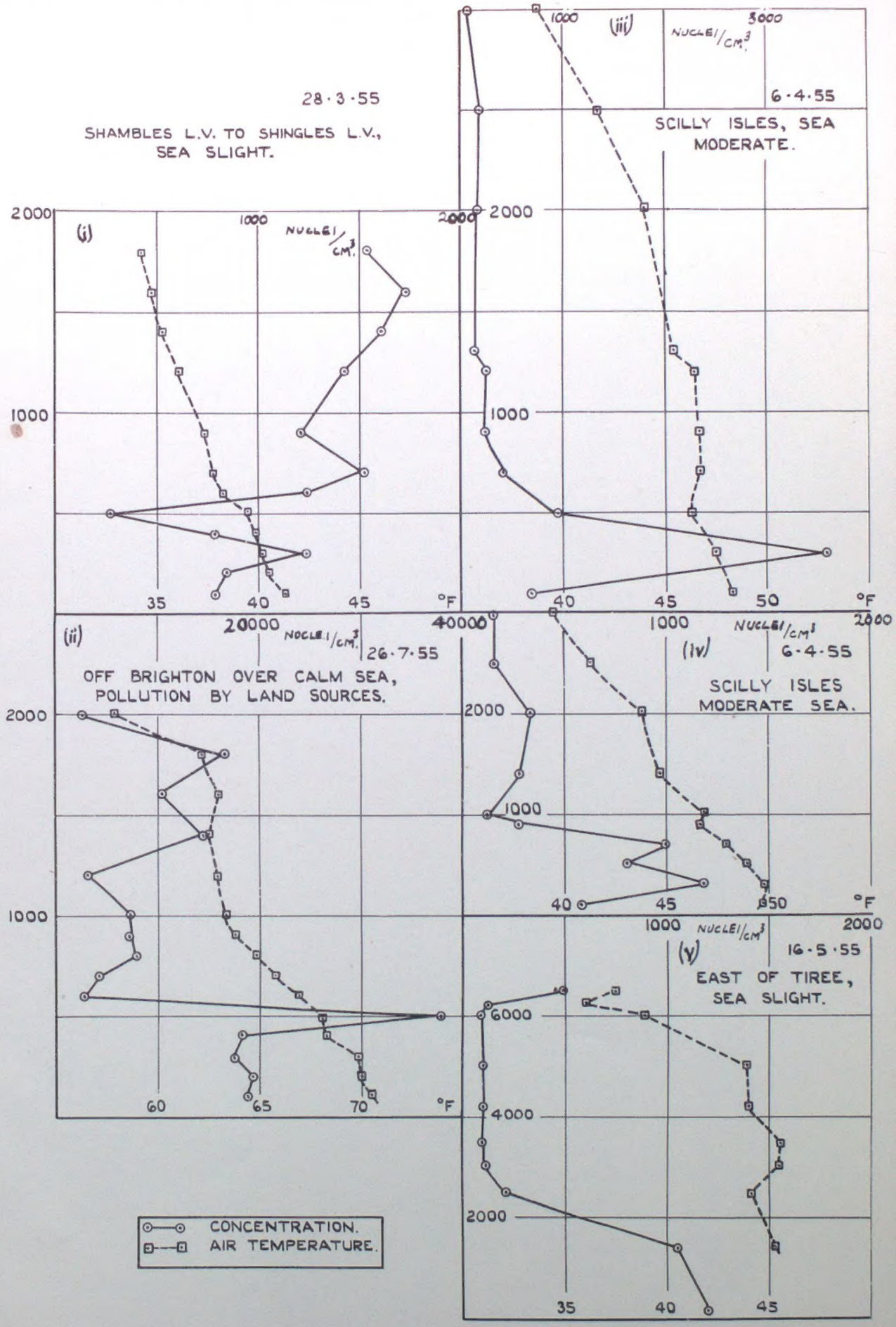

FIG. 3 b. VARIATION OF CONDENSATION NUCLEUS CONCENTRATION WITH HEIGHT OVER SLIGHTLY DISTURBED SEA.

Nº MET. RES. FLT.
DR.
TR. O.W.H.
CH.
APP.

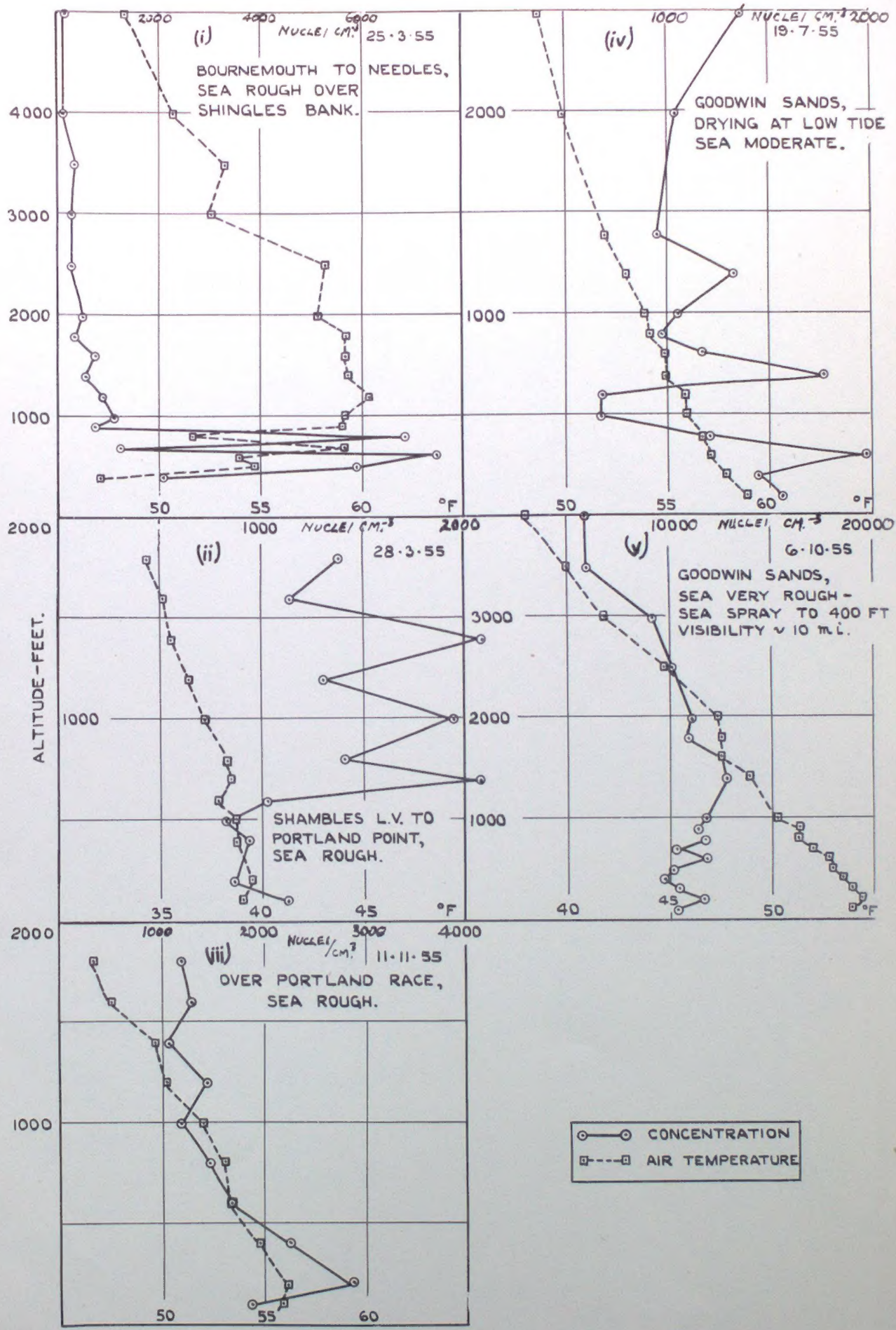

FIG. 3c. VARIATION OF CONDENSATION NUCLEUS CONCENTRATION WITH HEIGHT OVER DISTURBED SEA.